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The cropping systems of the Central Dry Zone of Myanmar: Productivity constraints and possible solutions

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ABSTRACT

The Central Dry Zone (CDZ) of Myanmar is home to an estimated 12 million people, provides 35% of Myanmar's grain cropping, but is underdeveloped and food-insecure. We examined the cropping systems of the CDZ to understand the biophysical drivers of those systems, the need for change to improve productivity and sustainability, and how future research and extension might be framed to best serve the rural communities. Data were sourced from (i) published empirical studies and web-based documents produced by the Myanmar Government and international agencies and (ii) a face to face survey of 190 Central Dry Zone farmers. Our analysis indicates that CDZ cropping systems have low productivity which threatens sustainability and future production. Farmers practice traditional cultivation and remove crop residues to use as animal feed, which together deplete soil organic matter reserves and expose the soil to physical degradation. The soils are generally coarse-textured with low water retention, high leaching potential and nutritionally deficient. Nutrient inputs from farm-yard manure and mineral fertiliser are also low. As a consequence, crop nutrient deficiencies are widespread across the CDZ and a major productivity constraint. Mineral-fertiliser use is increasing however, but farmers are conscious of the need for high-quality advice on how best to use these inputs. A narrow range of crops is grown in the CDZ with ca. 80% of the land used to grow pulse and oilseed legumes and sesame and sunflower, but few cereals. The lack of crop diversity exposes farmers to market price fluctuations and the lack of balance between broadleaf and cereal crops results in disease and yield loss. Climate changes further threaten the sustainability and economic viability of grain cropping with increasing temperatures, more erratic rainfall and fewer but more intense rainfall events during the monsoon. Consequences are more floods and dry periods and increased risk of soil erosion. The imperative now is to transition the upland cropping of Myanmar's CDZ to embrace the basic elements of conservation agriculture, i.e. crop diversity, effective weed control, in situ retention of crop residues, optimised crop nutrition and minimal-to-zero soil disturbance, to sustainably increase crop water use-efficiency and system productivity.

1. Introduction

Agriculture is the most important economic and social sector in Myanmar, accounting for ca. 30% of GDP and > 60% of the workforce (MOALI, 2016). Grain cropping dominates with rice (*Oryza sativa*) grown on ca. 7.0 Mha, pulse and oilseed legumes on 5.5 Mha and non-legume oilseeds on 2.0 Mha (MOALI, 2016; FAOSTAT, 2017). Black gram (*Vigna mungo*), green gram (*Vigna radiata*), groundnut (*Arachis hypogaea*) and chickpea (*Cicer arietinum*) are grown in rotation with lowland rice while, in the upland systems, green gram, groundnut, pigeonpea (*Cajanus cajan)* and cowpea (*Vigna unguiculata*) are commonly grown in sequence with sesame (*Sesamum indicum*) and the coarse grains, pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and maize (*Zea mays*). Rice production is concentrated in the lower half of Myanmar with upland cropping primarily in the middle of the country in the Central Dry Zone (CDZ) (MOALI, 2016).

The legume and oilseed crops represent 44% of Myanmar's total crop area compared with just 5–10% for China, Laos, Bangladesh and

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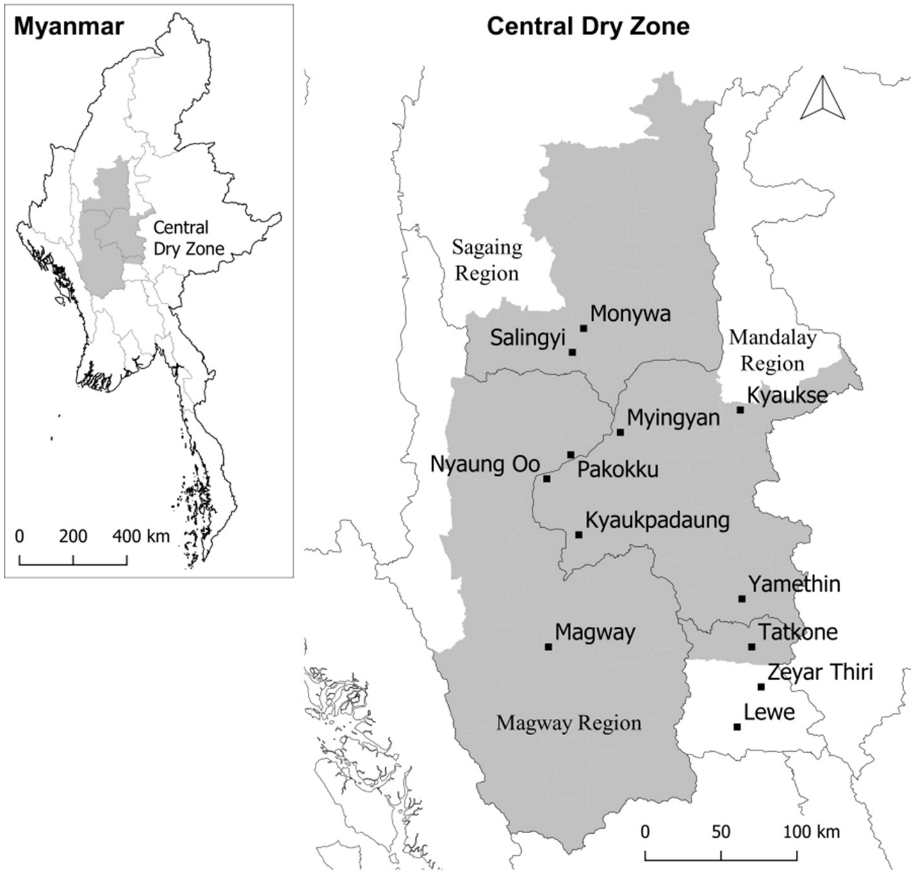

Fig. 1. Map of Myanmar with the Central Dry Zone (CDZ) highlighted. The 190 farmers involved in the survey were from the 12 township areas in the Sagaing, Mandalay and Magway Regions and the Nay Pyi Taw Union Territory.

Thailand (MOALI, 2016; FAOSTAT, 2017). The difference between Myanmar and its close neighbours reflects the large areas of upland cropping in the country that are not suitable for rice and the substantive but volatile market in India for pulses (Raitzer et al., 2015; World Bank Group, 2016). Myanmar is currently the world's second largest pulse exporter (World Bank Group, 2016).

Myanmar's agriculture has underperformed during the past five decades. Low productivity, unequal distribution of land and other assets, the high cost of credit, and volatility of grain production and price have all been identified in numerous reports as key factors in the underperformance (e.g. Haggblade et al., 2013; World Bank Group, 2016). These reports, based primarily on production statistics, demographics and responses in livelihoods surveys, were strong in socio-economic analysis but lacked depth in the analysis of biophysical aspects of farming systems that underpin improved rural livelihoods.

Underperformance is nowhere more evident than in the CDZ (Vaughan and Levine, 2015), the centre of rainfed, upland cropping in Myanmar. The Asian Development Bank concluded that the CDZ is one of the most food-insecure, water-stressed, climate-sensitive, natural resource-poor and least-developed regions of the country (ADB, 2016). The 2013 LIFT household survey (LIFT, 2014) reported that 18% of CDZ households had inadequate food, and more than a quarter of young children were underweight.

Farmers in the CDZ face significant additional challenges that range from negotiating the transition from subsistence farming to the market economy, through to dealing with uncertainties in the weather and managing soils that are mostly coarse-textured with low organic matter, low water holding capacity and little nutrient buffering (Birchall et al., 2017; Guppy et al., 2017). These challenges are compounded by the increasing scarcity of labour and a climate that has become progressively more hostile (Vaughan and Levine, 2015; Cornish et al., 2018). Additionally, and in order to fulfil a broader role benefitting Myanmar's people and economy as a whole, the CDZ farmers need to improve farm productivity and profitability (ADB, 2014; World Bank Group, 2016).

The study we report here arose from a project focussed on the legume-based systems in Myanmar's CDZ within a broader context of sustainable rural livelihoods. As defined by Pretty (2008), livelihoods are considered sustainable when they can cope with stresses and shocks and maintain or enhance capabilities and assets both now and in the future without undermining the natural resource base. We aimed to identify and recommend directions of change for the farming systems of the CDZ, based on a comprehensive biophysical analysis of those systems. We wanted to know if and how the CDZ farmers were coping with current changes and uncertainties and what other changes were required to improve productivity and sustainability. In this paper, we initially define grain cropping of the CDZ, based largely on empirical data and the many web-based documents produced and/or commissioned by the Myanmar Government and international agencies working in Myanmar. We then report a face to face survey of 190 CDZ farmers and relevant comments from 7 associated farmer group meetings involving 60 of those farmers, conducted to gain farmer insights into the (i) changing nature of the CDZ's farming systems, (ii) major factors affecting productivity of the CDZ systems, and (iii) technology and information gaps to be addressed going forward.

2. Materials and methods

2.1. Defining the Central Dry Zone and its agriculture

Defining the CDZ and its agriculture is based on a small number of journal and conference articles, including some of our own research, with much of the information derived from online documents and other

'grey literature' produced by Myanmar Government agencies or commissioned by international agencies working in Myanmar. National and Regional statistics were available for crop areas, grain yields and total production (FAOSTAT, 2017; MOALI, 2016; U Than Htut, Land Record and Statistical Department, MOALI, personal communication). To estimate crop areas in the CDZ, we assumed that the CDZ contains 25%, 80% and 80% of the land area of Sagaing, Mandalay and Magway Regions, respectively, and 70%, 80% and 95% of the crop lands in those same Regions (LIFT, 2012; MIMU, 2013; Vaughan and Levine, 2015; Tun et al., 2015).

2.1.1. Geography

The CDZ is a relatively low-lying area in the middle of Myanmar of ca. 80,000 km^2, i.e. 12% of the country's land area, within latitudes 19.5–23.3° N and longitudes 94.3–96.4° E and between the mountain ranges to the north, east and west and the Ayeyarwady River delta to the south (Fig. 1).

2.1.2. Population, family and farm and size and related socio-economics

An estimated 12 million people live in the CDZ, equivalent to 23% of the total population of Myanmar (Vaughan and Levine, 2015; IWMI, 2015; MOALI, 2016). There is very little ethnic diversity in the CDZ, with data from the 2013 LIFT household survey indicating 99% of respondents belonging to the Bamar ethnic group (LIFT, 2014). Of the total CDZ population, ca. 80% or 10 million are classified as rural (FAO, 2014; MOALI, 2016).

The average CDZ village contains 170 households, with each household consisting of 4.9 persons and 60% of households undertaking farming activities (LIFT, 2014). From those statistics, we calculate that there are ca. 1.2 million farmers (farming families) in the CDZ, although not all are land-holders. The average farm size is 3–4 ha with large variations in size, from < 1 ha to > 20 ha (LIFT, 2012, 2014; FAO, 2014).

Pulses and groundnut are regarded by CDZ households as cash crops, rather than sources of household food. The top four income generators for CDZ households in the 2013 LIFT survey were, in descending order: the sale of pulses and groundnut; sale of labour; sale of coarse (cereal) grains and receipts from small businesses involved in production and trading. The same survey identified the major household foods to be rice, vegetables and oil, with pulses a distant fourth (LIFT, 2014).

Households in the CDZ are generally under financial strain, with ca. 80% taking out loans in the previous 12-months (LIFT, 2014). Loans were used primarily for food and agricultural inputs with, unsurprisingly, the wealthier households spending relatively more on agricultural inputs than food and the poorer households the opposite. About one-third of households indicated that their debt was increasing (LIFT, 2014), presumably leaving little capacity to invest in innovation or to take risks with unproven technology.

2.1.3. Climate and climate change

Although the climate of the CDZ is classified as tropical monsoon, the region receives substantially less rainfall, i.e. average of ca. 700 mm and range 500–1000 mm annually, compared with 2000–5000 mm for the remainder of the country (FAO, 2009; Tun et al., 2015; IWMI, 2015). Rainfall is concentrated into a 5–6 month period, commencing around mid-May and finishing late October to mid-November (McCartney et al., 2013). Variable monsoon duration and rainfall amount, in combination with soils of generally low water holding capacity, makes the CDZ a challenging cropping environment (Vaughan and Levine, 2015; Cornish et al., 2018).

To better understand the opportunities and risks of rainfed cropping on the CDZ, Cornish et al. (2018) analysed long-term climate data in combination with soil water modelling to estimate the average length of the growing season and its variability. Taking Magway Township area in the southern part of the CDZ with its sand/sandy loam soils as an example, they found that the average growing season was sufficient for two short-duration crops such as sesame and groundnut (total of 177 days), or an intercrop system combining the two short-duration crops with the long-duration and deeper-rooted pigeon pea (total of 200 days). These findings provided agro-ecological support for the cropping systems in widespread use, but also brought into focus the importance of managing variability around the 'average' growing season.

Rainfall variability can lead to water stress at any time during the growing season, but the greatest risk identified by Cornish et al. (2018) was associated with variable growing season length and the risk of terminal drought, especially with the second crop in a double-crop system. They also concluded that the risk of terminal water stress was of greater concern than the risk of establishment failure of the first crop early in the wet season, provided farmers have the resources to re-plant.

Farmers often reduce inputs to manage the risk of financial loss in the event of low-rainfall, but this approach limits the capacity of the crop to produce higher yields in better years. Managing crops to achieve nearer the water-limited potential inevitably increases yield variability to reflect rainfall variability. Cornish et al. (2018) suggested that in rainfed environments with variable rainfall, yield variability with high average yields is an indicator of both high productivity and sustainability, which is contrary to the common view that agricultural sustainability is characterised by high output stability (Pretty, 2008).

Water balance modelling also revealed the magnitude of deep drainage as a component of the annual water balance (Cornish et al., 2018). Deep drainage averaged about 10% of the growing-season rainfall and occurred in 60% of years, albeit with large inter-annual variation. Deep drainage was most likely to occur later in the monsoon and be significant for the second crop (termed post-monsoon by local farmers) or at the time of flowering of pigeon pea. The agronomic challenge of deep drainage in sandy soils is leaching of soluble nutrients, most notably nitrogen (N), potassium (K) and sulfur (S) (Sitthaphanit et al., 2009). The overall conclusion of Cornish et al. (2018) was that water use efficiency of both individual crops and cropping systems could be substantially and sustainably increased, but they noted significant challenges to doing so.

Several authors have documented climate change in Myanmar (e.g. Slagle, 2014) noting that temperatures were generally increasing as was the frequency of heavy (extreme) and sometimes untimely rainfall events. Analyses of climate change in the CDZ indicate increasing temperatures and increasingly erratic rainfall with some reports suggesting significant declines in total amount (FAO, 2014; ADB, 2016). While the decline in rainfall at Magway since the early 1950's had been small and non-significant, the fall in June–July rainfall had been substantial (Cornish et al., 2018). This is the critical period for first crop establishment and may be far more important than a small decline in total rainfall. A further aspect of the changing climate was a sharp decline in the number of rainy days in the growing season, with fewer but larger rainfall events (Fig. 2a). The immediate consequence of this is an increase in the period of time the soil surface is dry (Fig. 2b), with implications for organic matter breakdown and crop nutrient uptake as well as for crop establishment.

Predictions of future climate in the CDZ vary although there is universal agreement that temperatures will continue to increase (e.g. ADB, 2016). At the same time modelling indicates little change in annual rainfall (ADB, 2016) but higher rainfall in the shortening monsoon with reduced rainfall in the dry seasons. The possibility of an increase in extreme rainfall events and flooding in the wet season and more and prolonged droughts in the dry season will create further challenges for the CDZ farmers in an already challenging environment (Slagle, 2014).

2.1.4. Soils

The soils of the CDZ are mostly alluvial in origin, classified as luvisols, vertisols, gleysols and nitisols (FAO, 2015; Htwe, 2015). Guppy et al. (2017) reported results of a survey of the surface, i.e. 0–10 cm,

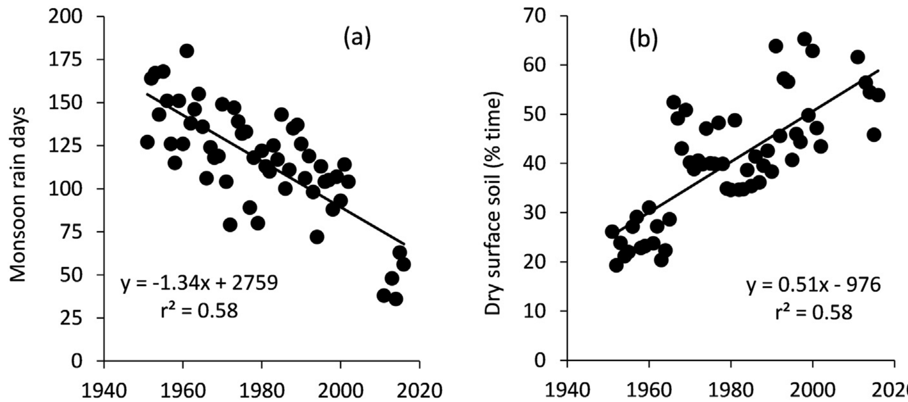

Fig. 2. The changing frequency of (a) rainy days during the monsoon and (b) its effect on surface soil water. Data for Magway Township in the southern part of Myanmar's CDZ, 1951 to 2016 (redrawn from Cornish et al., 2018).

Table 1
Average and ranges of values for 319 surface (0–10 cm) soils sampled in 2013 from farmer fields across the Sagaing, Mandalay and Magway Regions of the CDZ and adjacent Nay Pyi Taw Union Territory (Guppy et al., 2017).

Soil test	Average	Standard deviation	Range
pH_{water}	7.7	0.77	5.0–9.7
Organic C (%)	0.45	0.34	0.05–1.61
% sand	76	17	11–97
% silt	13	11	1–59
% clay	11	9	2–69
EC (dS/m)	0.10	0.11	0.01–0.80
Available (alkaline $KMnO_4$)-N (mg/kg)	42.9	18.4	12.0–99.0
Available (Olsen)-P (mg/kg)	6.5	5.1	0.1–31.6
Exchangeable K (cmol/kg)	0.27	0.25	0.02–2.71
Exchangeable Na (cmol/kg)	0.48	0.73	0.01–4.28
Exchangeable Ca (cmol/kg)	8.8	7.9	0.2–71.0
Exchangeable Mg (cmol/kg)	4.5	4.7	0.2–19.6
ECEC (cmol/kg)	14.1	11.4	0.6–72.8
Water-extractable S (mg/kg)	10.3	30.6	0.4–315
DTPA-extractable Zn	0.68	1.51	0.0–25.4
DTPA-extractable Fe	9.9	6.2	0.2–35.5
Hot water-extractable B	1.2	1.1	0.1–7.2

soils of 293 farmer fields across the CDZ and 26 fields in the Nay Pyi Taw Union Territory adjacent to the CDZ. They considered all 319 soils together and concluded that the majority were near neutral to alkaline (pH_{water} range 5.0–9.7, average 7.7) and low to very low in organic carbon (C) (range 0.05–1.6%, average 0.45%), clay contents (range 2–69%, average 11%), and plant nutrients (Table 1).

For key macronutrients, Guppy et al. (2017) reported that 61, 35 and 48% of the surface soils had less than the critical values for phosphorus (P), S and K, respectively. Multiple deficiencies (P, S and K) were recorded for 18% of soils. Sodicity did not appear to be a problem; however, 28% of soils had pH values > 8.3, suggesting potential for sodicity deeper in the profile. Notwithstanding the generally impoverished nature of the surveyed CDZ soils, very high values for the various soil measures were recorded for individual fields suggesting luxury application rates for organic and/or mineral fertilisers by some farmers.

More than half the surface soils had < 10% clay, indicating the coarse-textured nature of most CDZ soils. The average clay content of the soils increased with increasing latitude, from an average of 4% clay in the Magway township area, Magway Region (latitude 20.13° N), to 24% clay in the Butalin township area, Sagaing Region (latitude 22.38° N), a distance of ca. 240 km to the north of Magway. This may have implications for soil fertility and crop productivity with regression analysis indicating positive relationships between % clay and available N and P, exchangeable sodium (Na) and magnesium (Mg) ($P < .01$). It also has implications for crop choice, for it is on these higher clay soils in the Sagaing Region that chickpea is widely grown after rice on stored soil moisture (Guppy et al., 2017).

Less is known of the nutrient status of the CDZ soils below the surface 10 cm. Deeper soils may contribute to plant nutrition, particularly if soluble nutrients are leached during the episodic drainage events identified by Cornish et al. (2018). Preliminary data from the southern part of the Magway Region indicated generally increasing clay content of soils with increasing depth, from an average 6% clay at the surface to 21% clay at 80–100 cm depth (Birchall et al., 2017). Clay in the subsoil may hold nutrients leached from the surface to be accessed by the deeper roots of growing crops (Guppy et al., 2017).

The physical state of the soil has the potential to impact crop productivity (e.g. Lal, 1995; Alakukkua et al., 2003; Vaughan and Levine, 2015), although the evidence for soil degradation in the CDZ is mainly observational rather than empirical. Tun et al. (2015) reported modelled erosion losses of 0–114 t/ha/yr, but noted that the data required to make such assessments are scant. Further research is needed to provide empirical evidence of erosion rates.

Tun et al. (2015) also reported impacts of soil degradation on crop productivity with farmers reporting yields in highly degraded areas that were 8–30% of those in less degraded areas. Farmers' perceptions as to what caused the soil degradation pointed more to the nature of the soil, topography and climate, rather than the fact that their soils had lost resilience through mismanagement. Consistent with the soil data from the Guppy et al. (2017) survey (Table 1), the > 600 farmers surveyed in the Tun et al. (2015) study regarded soil sodicity, acidity and salinity as minor issues.

2.1.5. Crops and cropping systems

The CDZ includes an estimated 35% of Myanmar's grain cropping area (assuming 80% of cropping across the Mandalay, Sagaing and Magway Regions is in the CDZ with a cropping intensity of 165% (MOALI, 2016; U Than Htut, personal communication, 2017). Central Dry Zone farmers cultivate 3.3 Mha land to grow 5.5 Mha grain crops. Major crop types are the 2.5 Mha pulse and oilseed legumes and 1.5 Mha sesame and sunflower (Fig. 3). Rice is grown as a rainfed monsoon crop and under irrigation in the CDZ, with the estimated planted area of 1.1 Mha representing 15% of Myanmar's total. On the other hand, an estimated 46% of Myanmar's pulse and oilseed legumes and 74% of sesame and sunflower are grown in the CDZ (MOALI, 2016; U Than Htut, personal communication, 2017).

While official data for cropping areas are likely to be reasonably accurate, the reliability of yield and production data has been questioned (e.g. Haggblade et al., 2013; World Bank, 2014). For the major crops of the CDZ, official average yields are ca. 4 t/ha for rice, 0.6 t/ha for sesame, 1.6 t/ha for groundnut pods, and 1.3–1.6 t/ha for the pulses

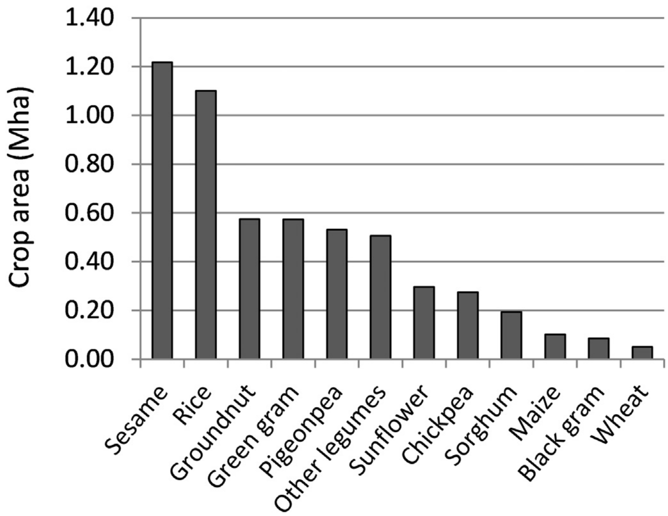

Fig. 3. Crop statistics for Myanmar's CDZ showing (a) areas of major crops planted in 2016/17 (source: U Than Htut, personal communication, agricultural statistical data for 2016/17 from Land Record and Statistical Department, MOALI, Myanmar).

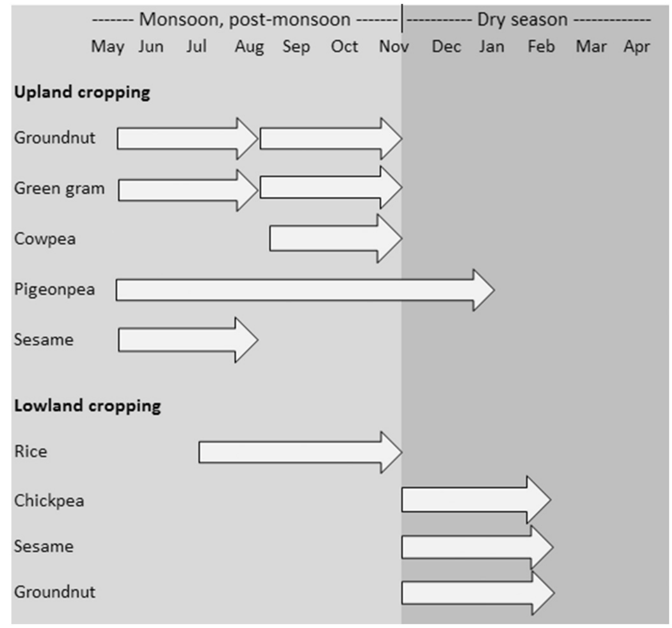

Fig. 4. Timing of the major upland and lowland crops in Myanmar's CDZ (source: U Than Htut, personal communication, agricultural statistical data for 2016/17 from Land Record and Statistical Department, MOALI, Myanmar).

(MOALI, 2016). Best farmer yields from > 1200 observations from a 2012 participatory rural appraisal (PRA) (unpublished data), a 2013 soil and cropping survey (Guppy et al., 2017) and two years (2016–18) of on-farm participatory research in the Magway Region (Birchall et al., 2017) were ca. 7.0 t/ha for rice, 1.4 t/ha for sesame, 3.0 t/ha for groundnut pods, 3.0 t/ha for chickpea and 2.2 t/ha for green gram and pigeonpea.

Average yields for the same crops in an independent survey of > 500 farms in the Sagaing Region of the CDZ were 33–75% of official yields and 15–40% of best-farmer yields (World Bank Group, 2016; Anderson et al., 2016). Our own aggregated data from the 2012 PRA, the 2013 soil and cropping survey and the two years of benchmarked crops in the Magway Region indicated average crop yield that were 50–90% of official MOALI (2016) yields and 30–50% of best-farmer yields. There is clearly substantial scope to improve crop productivity.

About 75% of cropping in the CDZ is upland during the monsoon (May to August) and post-monsoon seasons (August to November, and August to January for pigeonpea) (Fig. 4). Note that the term post-monsoon refers to the second crop during the monsoon, not the dry season after the monsoon. Crops grown by individual farmers in the upland and lowland systems are a combination of the crops in Fig. 3 plus other crops, such as vegetables and other pulses (see also LIFT, 2012; IWMI, 2015). The long-duration pigeonpea is often intercropped with either sesame, groundnut, green gram or cowpea grown in succession in monsoon and post-monsoon seasons (U Than Htut, personal communication, agricultural statistical data for 2016/17 from Land Record and Statistical Department, MOALI, Myanmar).

Cultivation for land preparation and incorporation of farm-yard manure (FYM), sowing, plant thinning in the case of sesame, weed control and harvest of groundnut are essential elements of CDZ farming practice. The majority of farmers, i.e. 75–90%, own draft animals and simple ploughs or tillage implements for these purposes (LIFT, 2014). Mechanised implements are far less numerous with data for 2013 indicating just 2.5% of CDZ farmers owned a power tiller and < 1% owned a tractor. The same LIFT (2014) publication indicated substantially greater ownership of both power tillers and tractors in the other zones of the country. The statistics are consistent with official Government figures for 2013 of an estimated nation-wide 6% ownership of power tillers and < 1% of tractors (MOALI, 2016).

2.1.6. Soil-borne disease and crop health

Upland cropping in the CDZ is dominated by the broadleaf pulse and oilseed crops. There are substantially fewer cereal crops in the CDZ, other than rice in the lowland areas, even though pearl millet, sorghum and maize are adapted to the area (MOALI, 2016; U Than Htut, personal communication). The imbalance between broadleaf and cereal crops renders the upland cropping systems particularly vulnerable to disease. Important are cercospora leaf spot (causal agent *Cercospora* sp.) and yellow mosaic virus for green gram, collar rot (*Aspergillus niger*) and root rot (*Sclerotium rolfsii*) for groundnut, fusarium wilt (*Fusarium oxysporum*) and wet root rot (*Rhizoctonia solani*) for chickpea, fusarium wilt for pigeonpea (*Fusarium udum*) and leaf spot (*Alternaria* sp.) for sesame. Root knot nematode (*Meloidogyne* spp) is a problem for pigeon pea, chickpea and mung bean (Han et al., 2001; YY Min unpublished data).

There are little quantitative data on the incidence and severity of fungal diseases of the legumes and sesame in the CDZ (Han et al., 2001) and the cost in terms of lost yield, although anecdotal reports indicate losses can be as high as 100% (YY Min unpublished data). Clearly, there is a need for more research on crop-loss assessment.

2.1.7. Contribution of legume N_2 fixation to the N economy of cropping in the CDZ

One positive aspect of the widespread cultivation of legumes in the cropping systems of the CDZ is their ability to fix atmospheric dinitrogen (N_2) in symbiosis with rhizobia, a soil bacterium (Herridge et al., 2008). The N_2-fixing legumes can thrive in N-impoverished soils (see Table 1) and in the absence of fertiliser N inputs. They can benefit the soil and following crops with N from their N-rich residues and are a highly-regarded feed for draft cattle (Angus et al., 2015). Although the economic benefits of the legumes, from reducing fertiliser N costs to providing animal feed to generating household income from the sale of grain, are clearly attractive to the CDZ farmers, the over-reliance on the legumes, at the expense of cereal crops, carries other risks as already discussed.

2.2. Farmer survey and associated farmer group meetings

The 20-question survey (see Supplementary Material) and

associated 7 farmer group meetings were conducted during a 2-week period in June–July 2017 by three of the paper's authors (DFH, MMW and KMMN) and by trained Department of Agricultural Research (DAR) and Department of Agriculture (DoA) personnel. The farmer survey consisted of face-to-face structured interviews about recent changes in cropping patterns, changes in the relative use of draft animals and mechanised implements, changes in the use of fertilisers and longer-term and recent changes in climate using a comprehensive survey questionnaire (Messer and Townsley, 2003). Structured interviews were used because it was considered less onerous for farmers to provide data this way than to fill out questionnaires, particularly where low literacy may pose a constraint (e.g. Wijnhoud et al., 2003). The farmer group meetings were designed to identify additional issues and concerns of the participating farmers that were not captured by the survey questions.

The surveyed farmers were selected by local DAR and DoA extension staff with the expectation that the cohort of farmers would provide a reasonable spread of demographics, farm attributes and farming practices and be representative of farmers of the district. The farmers represented three classes of cropping: rainfed ($n = 116$), irrigated ($n = 34$) and a mixture of both (n = 34). For most questions, the farmers' responses were aggregated. Of the 190 farmers surveyed, 17 were from the Sagaing Region, 86 from the Mandalay Region, 35 from the Magway Region and 52 from the Nay Pyi Taw Union Territory on the south-eastern edge of the CDZ (Fig. 1). The farmers lived in 33 villages in 12 township areas: Monywa and Salingyi in the Sagaing Region; Kyaukse, Myingyan, Nyaung Oo, Kyaukpadaung and Yamethin in the Mandalay Region; Pakokku and Magway in the Magway Region; Tatkone, Zeyar Thiri and Lewe in the Nay Pyi Taw Union Territory.

The surveys were conducted in Burmese, the local language, and later translated into English. The completed questionnaires were encoded and the data entered into Excel. All units were standardised, which involved converting Myanmar units to International Standard units. Myanmar farmers quantify grain production in terms of volumes and yields are all recorded as baskets/acre. The weight of grain in a full basket depends on the crop as follows: paddy rice 20.9 kg, groundnut in shell 11.3 kg, sesame 24.5 kg, green gram and pigeonpea 32.7 kg and chickpea 31.3 kg.

3. Results and preliminary discussion

3.1. Farmer survey and farmer group meetings in the CDZ

The 190-farmer survey and associated farmer-group meetings were conducted to confirm our analysis of the CDZ cropping systems and to gain additional farmers' perspectives about perceived changes in climate and cropping practices, particularly related to crops grown, the use or otherwise of power (mechanised) implements rather than traditional draft animals and relative uses of organic (FYM and composts) and mineral fertilisers.

3.1.1. Current and changing cropping patterns in the CDZ

Data on cropping systems and crop yields for the surveyed farmers were consistent with previously-presented data for the CDZ as a whole. Rainfed (upland) cropping dominated grain production by the surveyed farmers, with 63% relying on rainfall alone and 19% on rainfall plus supplementary irrigation sourced from wells, dams, local reservoirs and rivers (FAO, 2014; IWMI, 2015; World Bank Group, 2016). The remaining 18% of farms were fully irrigated. For the upland systems, crops in descending order of sown areas were groundnut, sesame, pigeonpea, chickpea and green gram (see Figs. 3, 4). In the irrigated and mixed irrigated/areas, rice dominated with sesame the next widely-grown crop. Average rice yields as reported by the farmers were high, ca. 4.0 t/ha and varied 1.6–5.2 t/ha. Average sesame, groundnut and pulse yields were much lower, ca. 0.5–1.1 t/ha and much more variable (0.1–2.5 t/ha).

The majority of farmers (67%) were growing the same number of crops as they did 5–10 years ago, with about equal numbers growing more (15%) and less crop types (18%). Reasons given for the changes that did occur were changing climate (42%), market prices (35%) and labour shortages (22%).

Most farmers (71–74%) had not changed the areas of legume (pulse, groundnut and other minor legumes) and cereal (sorghum, millet, maize) crops on their farms during the past 5–10 years. However, 12% were growing more legumes versus 6% growing more cereals. The small changes in legume areas were driven by market forces (37%), changing climate (35%) and labour shortages (27%). For the cereals, changes in areas planted were linked to market forces (35%), reduced demand for animal feed (28%) and labour shortages (22%). The overwhelming use of the cereals was as on-farm fodder (79%) with only 21% of farmers indicating that they sold cereal produce off-farm.

In the farmer group meetings, the issue of root and collar rots (diseases) of the pulses, groundnut and sesame, particularly in the heavier clay soils, was highlighted with yield losses said to be substantial in some cases.

3.1.2. Changing use of mechanised implements in the CDZ

Just 10% of farmers in the survey owned a tractor, with another 65% hiring a tractor for specific purposes, usually land preparation. Ownership of power tillers was slightly higher at 17% but fewer farmers hired them (35%). Almost 100% of farmers interviewed either owned draft animals (68%) and/or hired them (25%).

More use was made of tractors and other power machinery for land preparation (19% net difference between more use and less use) and harvesting (14% net difference), compared with 5–10 years ago (Table 2). There was no evidence of increased mechanisation of planting and weeding.

With more mechanisation of land preparation and harvesting, there was less use of draft animals for these tasks (Table 2). The greatest net changes in draft animal use (differences between more use and less use) were for planting (net 21% increase) and weeding (net 16% increase). So, it would appear that even though farmers are using more powered implements, they still rely on draft animals for certain tasks.

Major issues that were raised in the farmer group meetings were that labour shortages were largely driving mechanisation and the use of herbicides. Many farmers owned or rented tractors for primary cultivation and were looking for other tasks that could be mechanised, e.g. weeding and harvesting. Farmers were starting to use herbicides but quite a few voiced concerns about the long-term effects of the herbicides on soil health. They were conscious that they and the people they looked to for advice, e.g. DoA, DAR and the resellers, knew little about the efficacious and safe use of herbicides. Clearly, technical expertise about herbicides in both private and government sectors needs to be bolstered as farmers in Myanmar's CDZ transition from draft animals and hand weeding to mechanisation and herbicides for land management and weed control.

Table 2

Changes in use of mechanised implements and draft animals for major cropping events during past 5–10 years (values are % respondents).

	More use	No change	Less use	Don't use
Mechanised implements				
Land preparation	39	24	20	17
Planting	10	34	7	49
Weeding	6	26	5	63
Harvesting	30	11	16	43
Draft animals				
Land preparation	26	38	25	10
Planting	27	55	6	12
Weeding	22	55	6	17
Harvesting	20	33	21	25

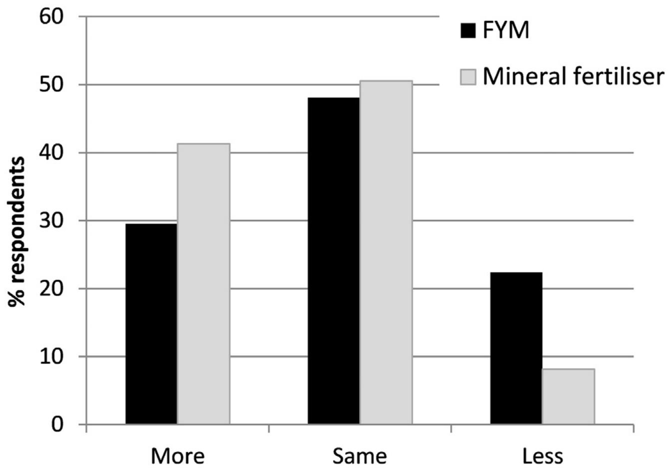

Fig. 5. Changes in the use of mineral fertilisers and FYM during the past 5–10 years in Myanmar's CDZ. Farmers were asked whether they were using more, the same or less mineral fertilisers and FYM than 5–10 years ago.

3.1.3. Changing use of fertilisers in the CDZ

Farmers were asked whether they had changed fertiliser practices during the past 5–10 years. Nearly two-thirds (63%) responded yes. Farmers were using relatively more mineral fertilisers and less FYM than 5–10 years ago (Fig. 5). The net difference between more use and less use was +12% for FYM and + 33% for mineral fertilisers. Changes in the relative use of FYM and mineral fertilisers were confirmed in the farmer group meetings with farmers acknowledging their loss of FYM supply as draft animals were replaced by powered implements. Despite the changes, mineral fertiliser rates remain very much lower than in neighbouring countries (Gregory, 2015; FAOSTAT, 2018). Low fertiliser use, together with the low soil fertility of most fields (Table 1), suggests that poor crop nutrition will continue to limit the productivity of crops.

The most important factor determining the type or brand of fertiliser purchased was nutrient content, with 82% of farmers rating it very important (Table 3). After that in importance were price (63% very important), advice from the DoA (58%) and availability (58%). Advice from neighbours/family members and resellers were rated the lowest of the 6 factors.

The majority of farmers (58%) considered that they had sufficient information on mineral fertilisers to make good choices about which fertiliser to buy and use. However, that left 42% of respondents either unsure about the adequacy of information or certain that they did not have the necessary information. When asked what information they were looking for, 46% wanted recommendations (application rates etc.) and guidelines for use, 31% wanted market and other relevant economic information, while 17% wanted information on the quality of the fertilisers. Only three farmers wanted information on the nutrient status of their soil.

Table 3
Rating of factors influencing the farmer's decision to purchase a particular type or brand of mineral fertiliser (values are % respondents).

Factor	Very important	Somewhat important	Not important
Fertiliser content	82	16	3
Fertiliser price	63	18	19
Advice from DoA	58	34	8
Availability	58	30	12
Advice from family, neighbour	37	44	19
Advice from fertiliser reseller	29	44	27

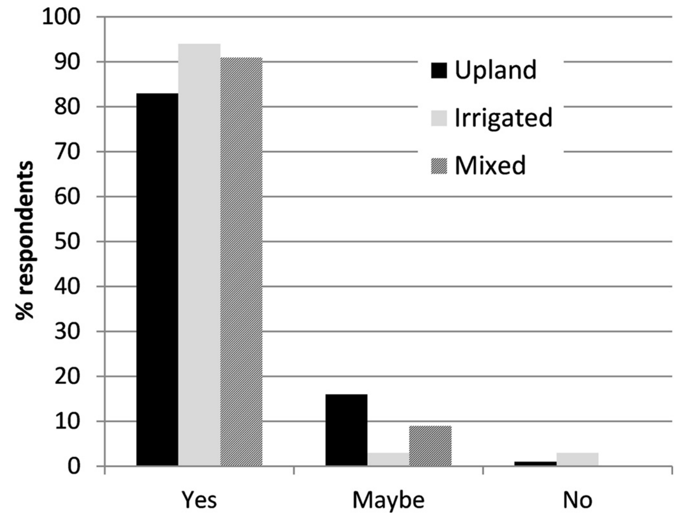

Fig. 6. Responses by farmer in Myanmar's CDZ as to whether the climate was changing and affecting the way they grew their crops.

3.1.4. Changing climate in the CDZ

Responses to the question of climate change were kept separate for the three classes of cropping, i.e. rainfed (n = 116), irrigated (n = 34) and a mixture of both (n = 34). Overwhelmingly and consistently across the three CDZ systems, farmers (83–94%) thought that the climate was changing and affecting how they grew their crops (Fig. 6). Some were uncertain (3–16%) and very few thought that climate was not changing (0–3%).

When asked for more detail about how the climate was changing, the most common response was that drought was more common (32% of respondents), followed by increasing temperatures (22%), more heavy rainfall (21%) and uneven, unpredictable rainfall (16%) (data not presented).

The final question was about specific aspects of climate change and its impact during the last 40–50 years. The responses generally confirmed responses from the previous question, with 84% agreeing that crop yields were more variable than before, 73–79% of farmers agreeing that rainfall was less now than before, that it comes less often, and when it does rain it is heavier (Fig. 7). A high percentage (74%) of farmers believed that the growing season was now shorter than before. About half of the farmers agreed that planting time is now later and that replanting is now more common than it was in the past.

4. General discussion

The objectives of this study were to analyse and describe the

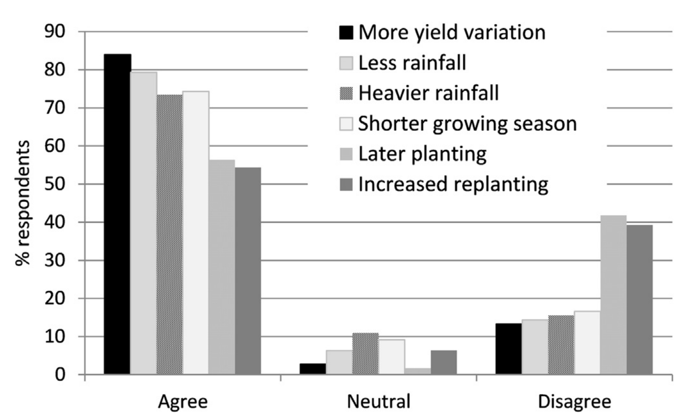

Fig. 7. More detailed responses by farmer in Myanmar's CDZ as to how the climate was changing and affecting the way they grew their crops.

biophysical aspects of cropping in Myanmar's CDZ and to identify technology and information gaps that could be addressed to improve productivity and sustainability. It does not follow that an understanding of the constraints will naturally lead to increasingly productive and profitable systems. The latter will only result from changes to farmer practice, supported by new technologies and accurate, relevant information provided by Government and private sector personnel. Practice change also requires farmers to have the necessary financial capacity, skills and confidence to implement change in a risky cropping environment. This will be a challenge given reports by farmers that levels of indebtedness are already increasing (LIFT, 2014).

4.1. Major constraints to the productivity of CDZ cropping systems

There is substantial scope to improve the productivity of CDZ cropping systems. For example, data from > 1200 observations indicated average crop yields were 42 and 50% of the best-farmer yields for chickpea and rice in rice-based lowland systems and 30–35% for sesame, groundnut, pigeonpea and green gram in upland systems. Analysis of the long-term soil water balance supports this conclusion, suggesting a large increase in average yields should be possible in the upland monsoon crops with no increase in climate risk, and in post monsoon crops with the risks being managed through an opportunistic approach to inputs (Cornish et al., 2018). However, there are significant barriers to realising this.

Crop nutrient deficiencies are likely to be widespread across the CDZ and a major productivity constraint (Birchall et al., 2017; Guppy et al., 2017; Weil, 2017). The soils are nutritionally deficient (Table 1) and mineral fertiliser use is low with nationwide data indicating average application rates of mineral fertiliser of only 21 kg/ha for N, 5 kg/ha for P_2O_5 and 3 kg/ha for K_2O (Gregory, 2015; MOALI, 2016). However, FYM provides the foundation for crop nutrition for most farmers at present. When nutrients derived from FYM are included, total inputs increase to 32 kg/ha for N, 14 kg/ha for P_2O_5 and 10 kg/ha for K_2O (Fig. 5; MOALI, 2016; Birchall et al., 2017). Even so, the combined N, P_2O_5 and K_2O rates for Myanmar are still substantially less than inputs from mineral fertilisers alone in neighbouring Bangladesh and Thailand (85–110 kg/ha for N, 24–40 kg/ha for P_2O_5 and 24–36 kg/ha for K_2O) (FAOSTAT, 2018). Efficient use of rainfall is not possible with low nutrient inputs, especially as soil organic matter is already low and provides little nutrient buffering (Table 1). Not only is the system less productive than it need be, but it is ultimately unsustainable.

One reason for low soil organic matter is that farmers commonly remove all above-ground crop residues with the harvested grain, using the residues for animal feed and returning only a fraction in FYM. This compromises the efficient recycling of nutrients between crops, and organic C inputs to soil are reduced. Because crop residues and soil organic C help to protect the soil from physical damage, the removal of crop residues increases the risk of erosion and the further loss of crop nutrients associated with soil loss (Tilman et al., 2002; Tun et al., 2015; Anderson et al., 2016). Therefore, in terms of both soil fertility and erosion management, there is a compelling argument in favour of greater in situ crop residue retention, albeit with implications for animal nutrition.

Mechanisation and reduced ownership of draft animals will result in an inevitable decline in the availability of FYM and farmers will have to rely more and more on mineral fertilisers. The transition from organic fertilisers, providing a slow release source of relatively balanced nutrition, to more labile mineral fertilisers will require skill on the part of the farmer to deliver effective crop nutrition (Tillman et al. 2002). Our survey indicated that farmers are generally using more mineral fertilisers than 5–10 years ago (Fig. 5) but they also recognise that they lack the knowledge of how to optimise crop fertiliser use and, in many cases, the funds to buy them. Research into the complementary use of FYM and mineral fertilisers and into fertiliser strategies such as split-application that potentially reduce leaching losses and improve fertiliser-use efficiency will, in part, address those issues (Birchall et al., 2017; Cornish et al., 2018). There will also be the need for effective extension that translates research outcomes to farmer practice.

A second productivity constraint, particularly in the upland systems, is disease resulting from the lack of crop diversity (Han et al., 2001; Vaughan and Levine, 2015). The ratio of broadleaf (groundnut, sesame and the pulses) and cereal crops is currently ca. 10:1 in the upland systems (75% of CDZ cropping) but closer to 1:1 in the lowland (rice-based) systems. Data from the CDZ farmer survey confirmed the ratio of broadleaf crops to cereals to be not only large but indicated that it was slowly increasing, driven by market forces, climate change, reduced demand for cereal-based animal feed and labour shortages.

Predictably, the CDZ farmers identified root and collar rots of the pulses, groundnut and sesame as major issues which, in extreme cases, can result in a total loss of yield. All are soil-borne diseases with the causal agents transmitted via crop residues. Removing crop residues from the fields may provide some relief by reducing disease inoculum levels (Veena et al., 2014). However, rotating different crops in the sequence to reduce disease inoculum levels is universally recognised as the most effective means of managing the problem (Kirkegaard et al., 2008; Angus et al., 2015).

The shortage of labour at critical times, such as sowing, weeding and harvesting, is a constraint to crop productivity in the CDZ (LIFT, 2014) and is largely responsible for the drive for mechanisation (Table 2). The farmers' perceptions of climate change as a constraint broadly agree with published reports based on weather data and modelling (Figs. 6 and 7; Slagle, 2014; ADB, 2016; Cornish et al., 2018). About 90% of the surveyed CDZ farmers, irrespective of whether their cropped land was rainfed or irrigated, considered the climate to be warming with rainfall occurring in fewer but larger and sometimes unseasonal events (Figs. 2, 6). There is also evidence that rainfall is declining in the June or June–July period, a critical time for crop establishment in the upland systems (McCartney et al., 2013; Cornish et al., 2018). At this stage, the upland farmers are partially adapting to the changing climate by planting later and being prepared to replant if seedlings perish in the absence of follow-up rainfall (Fig. 7). As the climate continues to change, more research resulting in system changes will be necessary.

4.2. Major constraints to the sustainability of CDZ cropping systems

Because the majority of cropping in the CDZ is currently low input, low productivity and based on cultivation and crop residue removal, the threats of surface soil degradation and loss may be more critical than other sustainability issues such as pollution from soil nutrients, pesticides and fertilisers leached into groundwater and surface waters (Tillman et al. 2002; Vaughan and Levine, 2015). This will change over time. For example, a large increase in mineral fertiliser use is predicted and, given the potential for N, K and S leaching, the protection of groundwater resources will rise in importance. Soil degradation and loss are also likely to be greater in the upland systems of the CDZ than in the irrigated and rainfed lowland (rice-based) systems. Bunded rice paddies are somewhat protected from erosive forces in contrast to the upland areas that are more sloped and exposed to the weather (Vaughan and Levine, 2015).

Quantifying the scale of soil degradation and loss in the cropping systems of the CDZ is problematic. The results of modelling indicating potentially high rates of erosion in Myanmar (Tun et al., 2015) may be misleading because of the scanty data available for the research. The rainfall analysis of Cornish et al. (2018) in the Magway region showed that the average growing season rainfall of 668 mm falls on an average of 177 days, resulting in an average daily rainfall of merely 4 mm. They found that since 1950, only one-third of years have had even a single rainfall event (day) of > 50 mm of rain. This does not suggest a generally high risk of erosion, rather erosion restricted to high-risk areas

such as steeper slopes or soils with impeded drainage. What is also important is that rain appears to be falling in fewer, bigger events, so the risk of erosion is likely to be increasing.

4.3. Solutions: technology and information gaps to be addressed

In both the upland and lowland (rice-based) systems of the CDZ, supplying nutrients with high efficiency to crops is critical to improved system productivity. Recent research of upland cropping in the Magway Township area indicated the benefit of split applications of the highly mobile N and S fertilisers (Birchall et al., 2017). As stated previously, farmers also need guidance about the complementarity of FYM and mineral fertilisers for different crops and at rates for different yield targets. Too often, recommendations target maximum yield, an approach that does not allow for farmers to set lower target yields that more closely match their capacity to access credit and their attitudes to risk.

In the upland systems dominated by the broadleaf crops, improved productivity and sustainability should also result from growing more cereals as disease-breaks, and implementing tillage and residue-management practices that retain biopores for good macrostructure and drainage, protect the soil surface from physical damage, and return sufficient organic matter to foster efficient cycling of nutrients and healthy soil biota. Such practices, together with effective weed control, optimised crop agronomy and nutrition and accurate climate analysis are the key elements of conservation agriculture (FAO, 2014; Anderson et al., 2016; Montgomery et al., 2017a, 2017b; Reeves, 2017; Weil, 2017).

Farmers, however, may have different opinions about constraints and their solutions. Montgomery et al. (2017a) reported that more than one-third of surveyed Cambodian farmers believed that repeated cultivation improved soil structure, soil fertility, water infiltration and plant growth and that it was impossible to plant a crop successfully without cultivation. Our experience is that the CDZ farmers have similar beliefs. A 2012 survey of upland cropping in the CDZ indicated 75% of farmers considered moisture conservation best achieved by keeping the soil bare (unpublished data). The use of organic mulching and cover crops was considered by just 2% of farmers as a moisture conservation practice.

Research has now been implemented in the CDZ to address effects of reduced tillage and crop residue retention on soil water, crop growth and grain production (e.g. Thu et al., 2016). The degree with which tillage and residue management practices change will be at least partially linked to the rate of mechanisation and associated reduction in demand for crop residues to be used as animal feed.

Access to stored water for irrigation in the CDZ is low (Vaughan and Levine, 2015). Improving watershed management and increasing the functionality of and access to irrigation systems should result in productivity gains, particularly for the rice-based systems. For the rainfed uplands, the prospects for a sustainable increase in groundwater extraction appear to be limited (IWMI, 2015), so the priority needs to be on increasing rainfall-use efficiency rather than developing water resources for irrigation.

Clearly, considerable effort will be required to effectively package and promote the benefits of conservation agriculture as an overarching practice for farmers in the CDZ. The challenges are not only technological but also relate to the knowledge embedded in the research and extension institutions in Myanmar and the means by which high-quality information is provided to the farmers (Cho, 2013). With respect of the latter, Government extension services in Myanmar are chronically under resourced (Haggblade et al., 2013) which leaves many farmers with low-quality or even a total lack of extension services.

5. Conclusions

Numerous studies have drawn attention to the under-performance of agriculture in Myanmar's CDZ, where ca. 80% of the land is used to grow mainly pulse and oilseed legumes and sesame and sunflower, but few cereals. This lack of crop diversity, particularly in the upland systems, carries both production and market risks. In addition to the current lack of crop diversity, repeated cultivation of soil, low application rates of mineral fertiliser and removal of crop residues for animal feed together limit productivity, deplete the soil of organic matter and increase the risk of surface soil degradation and soil erosion. Technology development will bring additional stresses, e.g. nutrient leaching will potentially increase as manure supplies diminish with mechanisation and farmers rely more on mineral fertilisers. Finally, rainfall patterns are changing, increasing the risks of flooding in lowland systems and low crop establishment and terminal drought in upland cropping.

Widespread adoption of best-practice conservation agriculture principles by CDZ farmers may have merit. Cropping systems that produce higher yields will not only provide more income for the farmer but also generate more residues to recycle nutrients and organic C back into the soil. To make it happen, farmers need high-quality technical advice from Government and commercial scientists, advisers and technical experts about modern farming practices and the efficacious use of mineral fertilisers, herbicides and pesticides. Although the general principles of conservation agriculture are well known, there is a need in Myanmar for research into the application of those principles to the unique biophysical and socio-economic environment of the country (Pretty, 2008). A participatory approach to this research, engaging farmers in their fields, should effectively address the challenge of modifying entrenched thinking and long-established practices (Tilman et al., 2002; Pretty, 2008; Anderson et al. 2018). Until changes occur, however, productivity of cropping in the CDZ will remain low and will likely decline further.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2018.12.001.

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